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AQUEOUS DEGREASING, PRECISION CLEANING, AND CLEANLINESS VERIFICATION PROCESSES

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ABSTRACT

The NASA Materials Science Laboratory at the John F. Kennedy Space Center (KSC) has been working with the base cleaning contractor, Wiltech, Inc.; the Development Testing Laboratory; and the Mechanical Engineering Design Division to develop and implement aqueous processes at the Base Cleaning Facility before 1995, when the use of chlorofluorocarbon 113 (CFC-113) will be banned.

The Base Cleaning Facility (BCF) operates to the KSC specification KSC-C-123, "Surface Cleanliness of Fluid Systems." Ground support equipment (GSE) and some flight hardware for the Space Shuttle program and other military or civilian programs at KSC and the Cape Canaveral Air Force Station (CCAFS) are processed through the cleaning facility. Developmental work in these field cleaning areas will be discussed in this paper.

INTRODUCTION

Recent links between chlorofluorocarbon 113 (CFC-113) and upper atmospheric ozone depletion and impending legislation have caused the John F. Kennedy Space Center (KSC) to plan the phase out of CFC's by 1995. CFC-113 is currently used at KSC as a precision cleaning and verification solvent. The Base Cleaning Facility must comply with the KSC specification KSC-C-123, "Surface Cleanliness of Fluids Systems." A surface cleanliness level of less than one milligram per 0.09 square meter (1.0 mg/ft^2) of nonvolatile residue (NVR) must be verified prior to hardware use.

It was obvious that one process or one solvent could not be used to replace CFC-113 for all applications. From the beginning, the project focused on using deionized water, ASTM D1193, Type II where possible. The next step was the selection of a method that could successfully transfer any surface contamination from the hardware to the solvent. The final step was the selection of an analytical method for quantitative analysis of NVR in each solvent.[1]

The developmental work currently at KSC includes the following areas:

- o Degreasing, Cleaning, Verification of
  - * Small components
  - * Large components
- o Degreasing, Cleaning of
  - * Flexhoses
  - * Small-diameter tubing/piping (25 - 150 mm, 1-6 inches)
  - * Large-diameter piping (150 - 350 mm, 6-14 inches)

PROCEDURES

Upon receipt at the cleaning facility, hardware generally follows a standard procedure (precision cleaning process):

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- o Initial 'rough' cleaning (degreasing)
- o Final Cleaning
- o Cleanliness Verification

The procedure/techniques used depends on the type and size of the hardware. Early studies have shown environmentally-friendly cleaners to be relatively inefficient without the aid of mechanical energy. Each of the processes developed at KSC employs a type of mechanical energy input.

During initial testing, 23 contaminants were identified for evaluation of detection levels. All contaminants, with the exception of fluorocarbons, were easily detected by the Total Organic Carbon analysis (TOCA) method.[1] [Fluorocarbons are liquid oxygen (LOX) compatible and, therefore, are not of great concern.] During the final phases of testing, four contaminants were selected, representing those most likely to be encountered during cleaning. These contaminants were:

- o Amoco Rykon II (hydrocarbon grease)
- o Chevron Molykote (molybdenum disulfide grease)
- o Dow Corning DC-55M (silicone grease)
- o Dupont Krytox 240 AC (fluorocarbon grease)

For NVR level verification, the analysis technique chosen was TOCA or Total Carbon Analysis (TCA) using a Dohrmann DC-190 High-Temperature (880°C) Combustion TOC analyzer. In the TOCA technique, a sample of water/contaminant rinse is introduced into the combustion chamber, converted to carbon dioxide, and measured by a nondispersive infrared detector. The carbon concentration is measured in parts per million (ppm). This is a simple technique that is easily adaptable to a production environment.[2]

SMALL PARTS

Small parts (fasteners, fittings, etc.) are first submerged in a 40-kHz US bath of Brulin 815GD for degreasing. The parts are then rinsed (40kHz US) and placed in an US bath of water/Zonyl FSN® particulate removal. After a final US rinse, the parts are placed in a separate clean container with a known amount of deionized water and submerged in a 25kHz US water bath for cleanliness verification. [It was determined that 25 kHz is more effective in NVR removal than 40 kHz; however, prolonged exposure to the lower frequency can cause damage to the metal surface.]

Upon completion of the US cycle, a 200 uL sample is drawn from the parts container and is injected into the analyzer for TOCA. The result, in ppm, is then converted into an equivalent NVR (ENVR) for pass/fail determination. The parts are then dip-sampled in a US bath of water/Zonyl FSN® for particulate evaluation.

During process development, three contamination levels were tested for each contaminant. The data indicated that each contaminant responded linearly with increasing concentration.[1] An equation correlating ppm and ENVR was then derived; a sensitivity factor (S), based on the individual contaminant responses and the probability of seeing each of the contaminants on any given part, was determined.

The equation for determination of an ENVR was determined to be:

$$ENVR = \frac{(TCs - TCb) * V}{Q * Vn * S}$$

where

ENVR = equivalent NVR, mg/0.09m^2
TCs = total carbon in sample, ppm
TCb = total carbon in blank, ppm
V = volume in parts container, mL
Q = surface area of parts in container
Vn = baseline volume, 500 mL
S = sensitivity factor, ppm carbon / mg

Once calculated, the ENVR can be compared to the cleanliness specification to make a pass/fail determination.

LARGE PARTS

Large parts, for verification purposes, are defined as any components too large to be cleaned using US techniques. Items range in size from less than 0.09 m^2 (1 ft ^{2}) in critical surface area (50-mm or 2-inch cryogenic service gate valve) to those large enough to require the use of a forklift to lift or transport. The components are of stainless steel construction and are typically used in oxygen systems. These parts are first degreased by a 30-minute immersion in a 60°C (140°F) bath of Brulin 815GD that is recirculated for turbulence. The parts are then rinsed with 82°C (180°F) water, immersed in a 60°C (140°F) bath with a submerged jet for 15 minutes, cooled with an ambient water rinse, and dried with breathing air. Verification is accomplished by impingement using the Impingement Verification System (IVS). A supersonic air/water nozzle at the end of a hand-held wand is manipulated manually to allow critical surface impingement. The water, which is injected at 32 mL/min upstream of the converging nozzle section, is accelerated through the nozzle to high velocities; this provides the energy to displace contaminants from the surface being verified and emulsifies the contaminants above their solubility in water.

During the process development, three contamination levels were tested for each of four contaminants. Like small part US verification, the data showed a linear relationship between increasing contamination level and TOC response. An equation correlating TC and ENVR was then derived, and a sensitivity factor determined.

The sensitivity factor, S (ppm / mg), is a measure of the level of responsiveness of the process. Sensitivity values were determined from the following equation:[2]

$$S = \frac{Va * (TCs - TCb)}{Vav * Cact * A}$$

where

Va = actual volume of effluent, mL
TCs = total carbon of sample, ppm
TCb = total carbon of blank, ppm
Vav = average volume of effluent collected, 45 mL (based on impingement duration, nozzle flowrate)
Cact = actual contamination level of valve body (mg / 0.09 m^2)
A = area of impinged surface (0.08 m^2)

From the average sensitivity values and weighting factors for each of the contaminants, an overall sensitivity factor was determined. This overall sensitivity factor was then used to calculate the ENVR using the equation:[2]

$$\mathrm{ENVR} = \frac{\mathrm{Va} * (\mathrm{TCs} - \mathrm{TCb})}{\mathrm{Vav} * \mathrm{S} * \mathrm{A}}$$

Once calculated, the ENVR can be compared to the cleanliness specification to make a pass/fail determination.

Currently, a component will be suspended above a catchpan and impinged for two minutes per 0.09 square meters of critical surface area. A beaker placed under the catchpan captures the water sample, after which any remaining water droplets on the catchpan are swept into the beaker by a low-pressure gas stream from the wand. Upon completion of the IVS process, a 200 uL sample is drawn from the beaker and is injected into the carbon analyzer for TCA. [TCA has been used in IVS analysis instead of TOCA, as is used in US analysis in order to reduce analysis time. Early IVS test programs indicated that the contribution of inorganic carbon to the total carbon content was not significant; the results of testing were not compromised by using TCA.]

CONVOLUTED FLEXHOSES

Cleaning of large-diameter flexhoses has historically resulted in one of the largest consumption of CFC-113. A "jet mole" attached to the end of a stainless steel, 6 mm (1/4 inch) diameter supply flexhose is inserted into the convoluted flexhose, which is vertically suspended from a tower. CFC-113 is pumped through the jet mole via the supply flexhose. A portion of the CFC-113 flow impinges the interior surface of the suspended flexhose for cleaning purposes, while the remaining flow is used to propel the jet mole/supply flexhose assembly along the suspended convoluted flexhose. The jet mole is a flow device having six radial holes that direct cleaning fluid to impinge on the surface to be cleaned; it also has six holes angled downward for propulsion. During the cleaning operation, copious amounts of CFC-113 were flushed through the convoluted flexhose; the effluent was captured in a 200 L (55 gallon) container for recycling. However, because the container was open to atmosphere, a large amount of CFC-113 was lost to vaporization during every cycle. A mixture of water, Brulin 815GD, and Zonyl FSN® is currently being studied to substitute for CFC-113 in the cleaning portion of the process.

SMOOTH-BORE FLEXHOSES

A preliminary look at aqueous methods of cleaning smooth-bore flexhoses has shown great promise. Brief testing has taken place with aqueous cleaners; however, a detailed test program is still to be conducted. Once other areas of concern are completed, cleaning and verification of smooth-bore flexhoses will receive further attention.

DEVELOPMENTS

There are several areas under early stages of development. These include cleaning systems for small diameter (less than 150 mm or 6 inch) and large diameter (150 mm - 350 mm, or 6 inch - 14 inch) tubing and piping.

SMALL DIAMETER TUBING/PIPING

The Turbine Brush Cleaner (TBC - patent-pending) provides an improved method of cleaning inside surfaces of small tubing/piping. Two sizes, 25 mm (1 inch) and 50 mm (2 inches), have been designed, built, and are currently undergoing testing at KSC. Water pressure provides the motivating force to spin a turbine attached to a circular brush and propel the brush downstream. The mechanical action of the brush, as well as the turbulence caused by the spinning turbine, aids the cleaning ability of the cleaner(s), which is mixed with water upstream. The TBC has successfully transversed around 90-degree bends. A magnetic sensor provides rotational and longitudinal position data while contained in any non-magnetic pipe. A pump and recirculation system minimizes facility requirements and waste streams; the effluent is filtered and reused.

The TBC offers advantages over existing rotating brush systems, which require flexible drive shafts and a facility air source for power. The elimination of the drive shaft allow a much more compact design that can transverse smaller diameters, turn up to 90-degree bends, and travel over longer distances. Another advantage of the TBC over conventional systems is the reduction of contamination of the cleaned sections of tubing, due to the absence of a trailing drive shaft. The prototype TBC system is designed for cleaning up to 50 mm (2 inch) diameter tubing/piping, up to approximately 30 meters (100 feet) in length.

The current test program involves cleaning of 1 m (3 ft) long sections of 25 mm (1 inch) and 50 mm (2 inch) diameter tubing that has been contaminated with a mixture of greases. The tubes were cleaned using the TBC, rinsed with deionized water, and analyzed for NVR using standard CFC-113 rinse methods. Initial results using Amber-Clean® indicate high removal rates (80-99%).

Future work includes determination of the effects of water rinsing and temperature on the cleaning efficiency. A series of cleaners will also be tested in the prototype system. The TBC design was submitted to the Patent Office at KSC in March of 1994.

LARGE DIAMETER PIPING

A spin-off of the IVS supersonic air/water nozzle is under development for pipe cleaning/verification. A concept system is in the design and prototype stages for verifying the cleanliness of large diameter pipe runs. Presently, it is anticipated to be able to verify piping systems as small as 150 mm (6 inch) outside diameter (O. D.), with the upper limit in the 350 mm (14 inch) range. Current concepts call for a spring-loaded, self-centering mechanism, capable of carrying a rotating sprayhead, which incorporates opposing supersonic BAir/water or gaseous nitrogen (GN_2)/water nozzles. The sprayhead rotation, and possibly movement along the pipe, would be driven by an air motor. In addition, a water collection system would be required for the collection of the effluent, from which the analysis sample must be drawn. Feasibility testing will begin upon completion of the prototype system.

CONCLUSION

KSC has made significant progress towards replacing CFC-113 in the cleaning and verification procedures. The quantity of CFC-113 used will be significantly reduced to approximately 25% of the original consumption level.

REFERENCES

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[3] "Supersonic Gas-Liquid Cleaning System," Technology 2003 Conference, Anaheim, CA, 1993.

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